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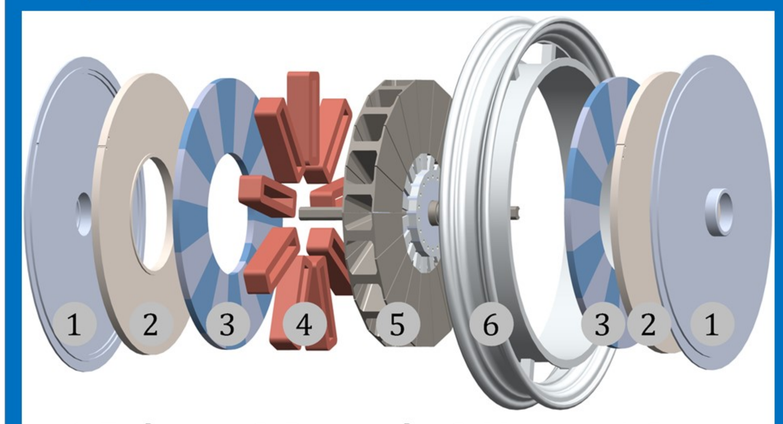
Summary

This work discusses design synthesis of a permanent magnet brushless DC (PMBLDC) machine using a finite element (FE) model. This work differentiates itself from the past studies by following a synthesis approach, in which many designs that satisfy a performance criteria are considered instead of a unique solution. The designer can later select a design, based on comparing parameters of the designs, which are critical to the application that the motor will be used. The proposed synthesis program is demonstrated by designing a segmented axial torus (SAT) PMBLDC motor for an electric two-wheeler.

Salient features:

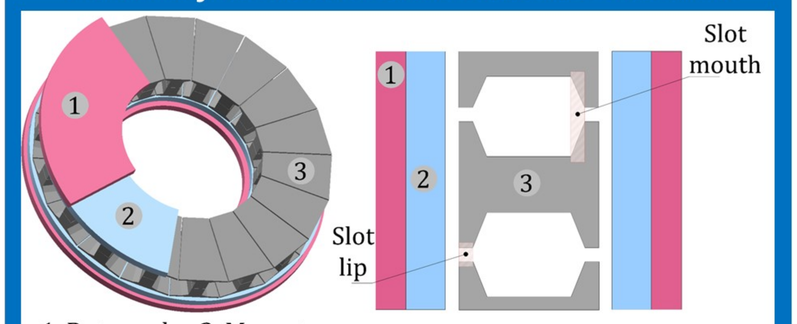
- The presented approach makes it easier to define constraints for a design synthesis problem.
- Even though, the time taken for each design iteration with FE model is considerably more compared to analytical or lumped parameter models; accurate results can be achieved with significantly less program development time.

Schematics of SAT PMBLDC motor



1. End cover, 2. Rotor yoke, 3. Magnets, 4. Stator winding, 5. Stator and 6. Wheel rim

Cutaway model of SAT PMBLDC motor



1. Rotor yoke, 2. Magnet, and 3. Stator

Design variables of SAT PMBLDC motor

1. Specification

1. Rated voltage
2. Rated Power
3. Rated Speed

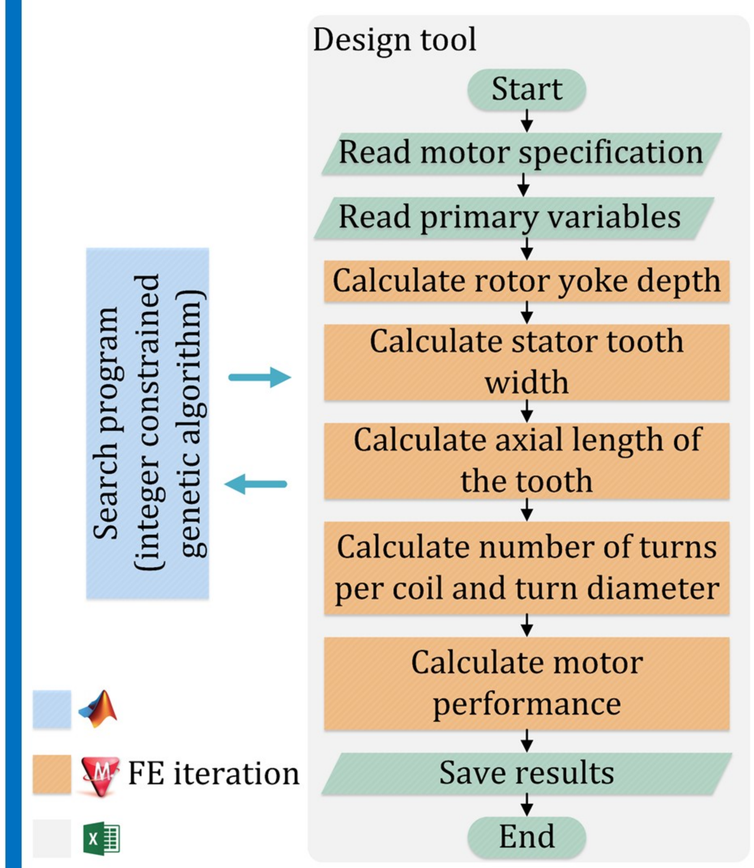
2. Primary variables

1. Number of stator
2. Number of rotor poles
3. Length of airgap
4. Outer diameter of stator
5. Gross slot fill factor
6. Width of slot opening
7. Depth of slot lip
8. Depth of slot mouth
9. Depth of magnet
10. Magnet overhang
11. Diameter ratio of stator
12. Max. current density
13. Ratio of pole arc to pole pitch
14. Max. rotor yoke flux density
15. Max. stator tooth flux density

3. Secondary variables

1. Width of stator tooth
2. Depth of rotor yoke
3. Diameter of a coil turn
4. Number of turns/coil
5. Axial length of tooth
6. Axial length of motor

Schematics of design synthesis program

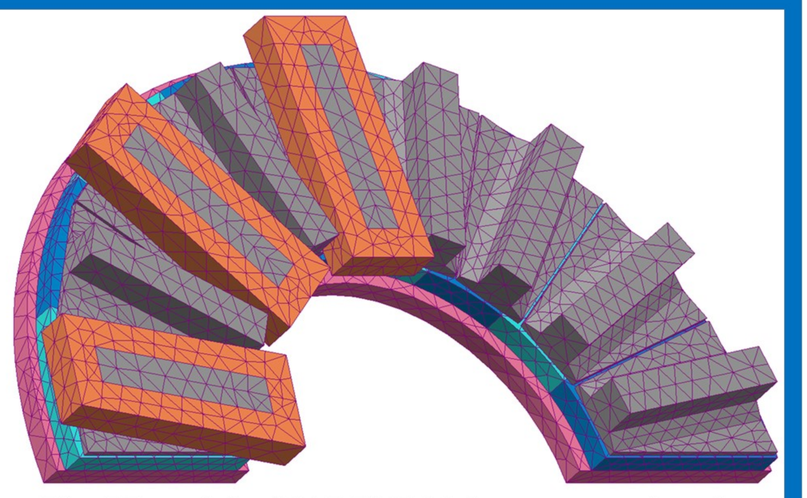


Design synthesis SAT PMBLDC motor for electric two-wheeler

Specification of the electric two-wheeler powertrain	
Maximum mass of vehicle including load	130 kg
Maximum speed of vehicle	32 kmh^{-1}
Time to reach maximum speed	15 s
Rated speed of motor	330 rpm
Rated torque of motor	20 Nm
Rated voltage of battery	48 V

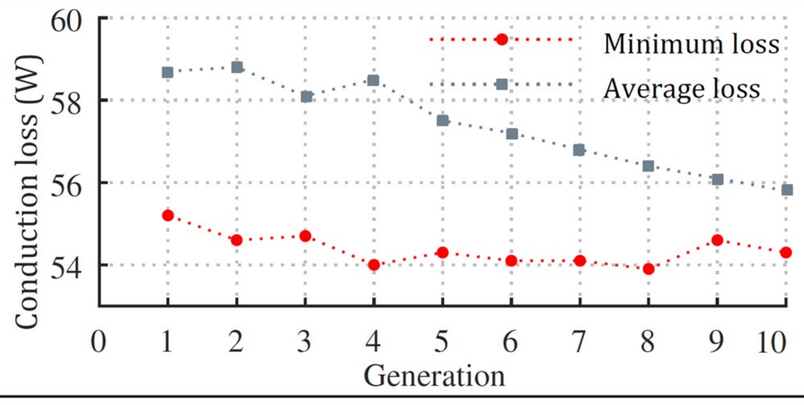
Range of optimisation variables	
Depth of magnet	7 to 10 mm; step = 0.5 mm
Magnet overhang	0%, 5%, 10%
Diameter ratio of stator	45% to 60%; step = 2.5%

Value of primary variables	
Number of slots	18
Number of poles	16
Length of airgap	0.4 mm
Outer diameter of stator	260 mm
Gross slot fill factor	50%
Width of slot opening	1 mm
Depth of slot lip	2 mm
Depth of slot mouth	2 mm
Current density of coil	4.5 Amm^{-2}
Ratio of pole arc to pole pitch	1
Max. flux density of rotor yoke	1.2 T
Max. flux density of stator tooth	1.6 T



The FE model of SAT PMBLDC motor used in the design synthesis

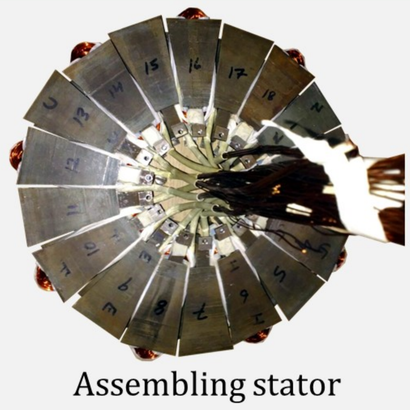
Results of optimisation



Optimised designs

Design	63	88	124	158	270	300	410	492
Thickness of magnet (mm)	7.5	9.5	8	7	7.5	7.5	7	7
Magnet overhang (%)	0	10	5	5	10	10	0	10
Diameter ratio (%)	50	52.5	50	45	48	45	45	45
Depth of rotor yoke (mm)	7	7	7	8	8	8	8	8
Number of coils	24	24	24	22	22	22	28	28
Axial length of motor (mm)	62	64	63	64	64	64	64	64
Phase resistance (mΩ)	36	35	36	34	32	34	56	56
Phase current (A)	28	28	28	28	29	28	22	22
Conduction loss (W)	57	56	57	55	56	56	54	55

Fabricated motor and components



Assembling stator

Assembling motor

Rotor yoke and magnet

Assembled motor